Fermilab FERMILAB-Conf-02/251-E October 2002

Calorimetry in CDF Run 2

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The integrated calorimetry environment of CDF Run 2 comprises the Run 1 sampling scintillator calorimeters, electromagnetic preshower and shower maximum detectors, new scintillating-fiber endplug detectors, radioactive source calibration systems, dedicated trigger paths, and new custom front-end electronics. Together they form a general-purpose calorimetry system which was successfully commissioned in 2000–2001. The initial performance is described here, along with a glimpse of first CDF Run 2 data.

1. Introduction

The Tevatron Run 2 began in the spring of 2001 after completion of major upgrades to the accelerator complex. The improvements have provided an increase in energy from $\sqrt{s} = 1.8$ TeV to 1.96 TeV, a decrease in bunch spacing from 3.5 μs to 396 ns, and expected instantaneous luminosities reaching 5×10^{32} cm^{-2} s^{-1} in Run 2b. To take advantage of the increased energies and collision rates, CDF underwent a major overhaul, with upgrades to almost every system [1]. With these improvements, CDF is poised to exploit the physics at the energy frontier for the remainder of the decade.

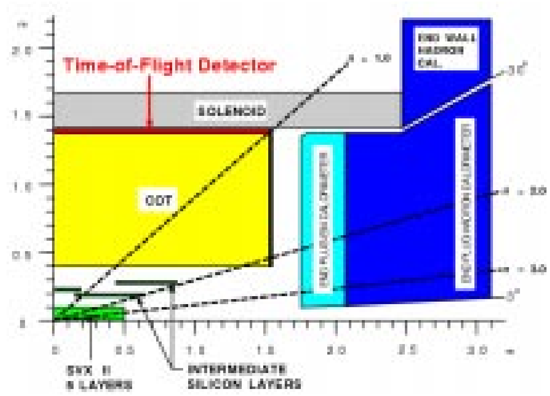

Figure 1. Cutaway quadrant of CDF2 without central calorimeters and muon chambers.

2. Calorimeter Endplug Upgrade

As part of the CDF Run 2 project [1], several portions of the calorimetry detectors were upgraded. While the original, central ($|\eta| < 1.1$), scintillator-based calorimeters [2] [3] were sufficient for the Run 2 operating conditions, the time response of the Run 1 gas endplug detectors was too slow for the decreased bunch spacing of Run 2, and they had to be replaced. The active elements of both the electromagnetic and hadronic portions of the new detectors [1] [4] are scintillator tiles read out by wavelength-shifting (WLS) fibers embedded in the scintillator. The new design has an improved sampling fraction, reduces forward gaps existing in Run 1, and utilizes technology similar to the central calorimeters, providing greater detector uniformity over the full solid angle to $|\eta| = 3.6$. Fig. 1 shows the new detectors positioned in the ends of CDF, and Fig. 2 shows the endplug support structure and photomultiplier tube (PMT) boxes.

2.1. Shower Maximum

The central shower maximum detectors [5] have had little problem with aging, so they remain for Run 2. These detectors consist of gas chambers with wire and strip elements. However, the slow gas chambers of the central preradiator and crack detectors do suffer from aging, and will be upgraded to more finely segmented scintillator detectors for Run 2b.

The plug shower maximum detector (PES) and preradiator were built into the new endplug detector. The PES consists of scintillating strips

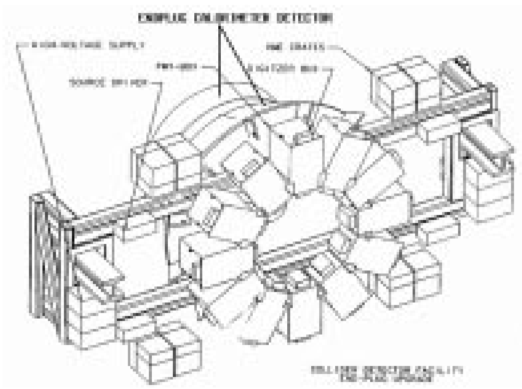

Figure 2. The new endplug calorimeter detector, its support structure, and the PMT boxes.

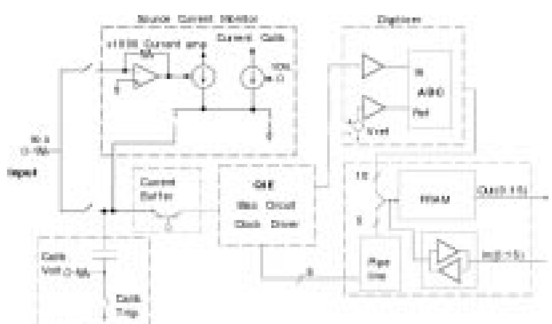

Figure 3. Simplified schematic of the CAFÉ card, containing a QIE chip and a 10-bit ADC.

and WLS fibers in two layers located $\sim$6 X_o into the PEM. The energy scale is well-matched to the plug electromagnetic calorimeter. The position is determined to within 1.5 cm, and will be improved using the forward silicon layers.

3. Electronics Upgrade

The move to scintillator-based calorimetry in the forward regions of the CDF detector has allowed for a common design for the readout electronics [6] throughout the central, endwall, and endplug calorimeters. Signal size estimates for collider energies up to 2 TeV indicated that the maximum PMT signal could be a factor of two greater than that seen in Run 1, requiring greater dynamic range than the previous 16 bits. In addition, with bunch crossings every 396 ns, the readout required fast digitization of signals with a large dynamic range. The Fermilab QIE (Charge Integrating and Encoding) [7] chip provided a multi-range solution for signal readout.

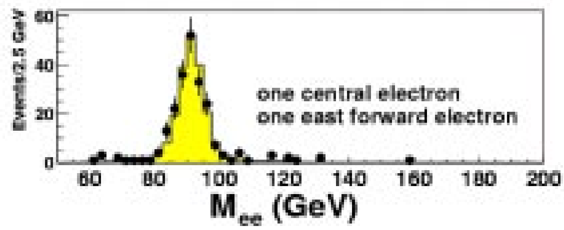

Figure 4. Preliminary CDF Run 2 Z$\rightarrow$ee distribution using 10 pb^{-1} of data, compared to MC (solid).

The QIE is a custom, multi-ranging circuit used originally in the KTeV experiment. It was modified for use in CDF for both calorimeter (QIE6) and shower max (SMQIE) readout, and again for use in both MINOS and CMS. The QIE architecture consists of a binary-weighted splitter and eight current ranges. The QIE6 together with a 10-bit FADC provides the needed 18 bits of dynamic range. These components, along with a FRAM and calibration/charge injection circuitry, are mounted on single-channel CAFÉ card modules (Fig. 3). The CAFÉ daughter cards are in turn mounted onto front-end VME ADMEM (ADC+MEMory) [8] boards. The ADMEMs provide the Level 1 trigger with transverse energy sums using Xilinx FPGA's. They also use a pipelined Level 1 buffer 42 clock-cycles (5.5 μs) deep (which provides deadtimeless readout), and four event buffers for pre-decision Level 2 storage.

3.1. Performance

The new calorimeter readout is performing well. Pedestals are stable over long time periods, and RMS values are typically 1.5–2.5 counts (5–6 MeV or 10–15 fC). The QIE has been extremely reliable, which bodes well for future experiments. Rare comparator failures make up the majority of the QIE problems, and periodic failures of tantalum capacitors comprise the main problems on the ADMEMs.

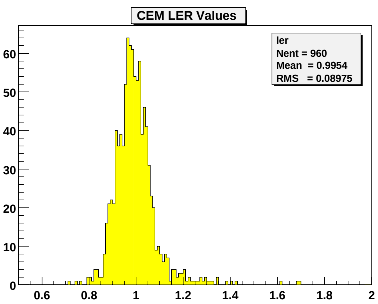

Figure 5. LER coeffs. for the EM calorimeter.

Figure 6. f_b, the fractional difference between p_T of the photon and the jet, as a function of η.

4. Calibration

The absolute energy scales were determined during the original test beam calibrations. These scales are maintained by measuring the response to radioactive sources. During the upgrade the ^{137}Cs source system was refurbished for the central detectors, and a ^{60}Co system was installed into the endplug. The energy scales are verified using data. Fig. 4 shows a sample of Z bosons having one electron in the central detector and one in the endplug. By construction the Z peak is at the correct location. For the hadron detectors, MIP peaks from J/ψ samples have shown that the central hadron calorimeter scale is within 4% of the Run 1 scale, and has been adjusted.

The relative energy scales are set using data. To correct for PMT gain and tower response variations, linear energy response (LER) coefficients are determined and applied to individual channels (Fig. 5). The responses are then tracked using a laser system for the hadron detectors, and LED/Xenon flashers for the EM detectors. The jet energy scales are corrected using dijet and

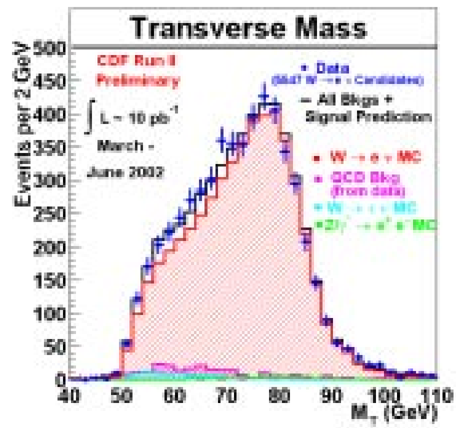

Figure 7. Preliminary CDF Run 2 W$\rightarrow e\nu$ sample using 10 pb^{-1}, including a MC prediction (non-filled plot) of signal plus all backgrounds.

photon-jet events by balancing the transverse momenta in individual events. For example, Fig. 6 shows $f_b = (p_T(\gamma) - p_T(jet))/p_T(\gamma)$ across the detector. The relative jet corrections are already quite good in the central detector region, and should be flat when the corrections are complete.

5. Conclusion

With the integrated calorimetry system in place and commissioned for Run 2, CDF can take full advantage of Tevatron collision data at the energy frontier. Analyses using the calorimeter, such as the initial W cross-section measurement [9] (Fig. 7) are well underway, establishing the tools for numerous exciting high-p_T physics measurements to come.

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